VOLUME 35 FEBRUARY 1951 NUMBER 2

Alaskan Eclipse Expedition

The National Bureau of Standards participated in an expedition to Attu Island, Alaska, to observe the total eclipse of the sun by the moon on September 11, 1950. The expedition was organized by Dr. John P. Hagen, of the Naval Research Laboratory, primarily to apply the methods of radio astronomy to the study of the eclipse at various radio frequencies. Included in the party of 10 scientists were Grote Reber and E. A. Beck of the Bureau's Central Radio Propagation Laboratory.

In addition to infrared, visible, and ultraviolet radiation, the sun is continually giving off energy at radio frequencies. In recent years, the techniques of radio astronomy have been developed for receiving and analyzing these longer wavelengths. This has made it possible to obtain information about the positions of stellar bodies and the matter in interstellar space that could never have been seen with an optical telescope. As the radio waves given off by the sun are received without difficulty through rain or fog, the methods of radio astronomy proved particularly valuable for observations in the cool, damp climate of Attu Island, where the eclipse was accompanied by a severe rainstorm.

The path of the total eclipse began in the Arctic Ocean and proceeded south-eastward across Siberia, the Bering Sea, and Attu, finally ending in the Pacific Ocean northwest of Hawaii. This path crossed United States territory only on Attu, a small piece of land, the last and most westerly of the Aleutian chain. Although the climate of Attu is most undesirable for making visual observations with an optical telescope, it seemed likely that significant results could be obtained there with radio apparatus.

The party spent approximately a month on Attu installing equipment and making preparations. The center of the path of the eclipse crossed the eastern end of the island. However, this location is very inaccessible both by land and by sea. The apparatus was therefore mounted upon an old airplane runway on Alexai Peninsula, one of the few open flat places on the island. At the place of observation, which was about 2 miles from the center of the path of totality, the eclipse lasted 73 seconds.

The high-frequency energy from the sun was collected by a mirror 10 feet in diameter having a focal length of 3 feet. An altiazimuth mounting made it possible to sight the mirror on the sun. The mirror served to focus the incoming radiation on an antenna placed at its focal point and connected to a high-frequency receiver. Signals thus received were amplified and applied to an automatic recorder, providing charts of intensity versus time for various frequencies.

Measurements of solar radio intensity were made at wavelengths of 3, 10, and 65 centimeters. The receiving equipment for use at the 65-centimeter wavelength, which was supplied and operated by the National Bureau of Standards, was a superheterodyne receiver having a 30-megacycle intermediate frequency and two stages of radio-frequency amplification. The

measurements were made from two to four times a minute beginning about 2 hours before the eclipse. The sky at an azimuth of about 90 degrees from the sun was used as zero reference. The sun was found to be quiescent and reasonably free from the transients that are often present during periods of solar activity.

Because of the radio waves sent out by the sun's ionized atmosphere, the apparent diameter of the sun at radio frequencies is always appreciably greater than at visual wavelengths. Consequently, all solar eclipses "viewed" with radio apparatus must appear to be annular rather than total. Preliminary results obtained from analysis of the data indicate that the apparent diameter of the sun exceeds that of the moon by 3, 7, and 11 percent, respectively, at wavelengths of 3, 10, and 65 centimeters.

Besides the ionized atmosphere of the sun, a variety of other solar phenomena are effective in generating radiation at radio frequencies. For example, the magnetic field associated with sun spots causes additional radiation at centimeter wavelengths to originate in the neighborhood of the spots. Thus, as the edge of the moon first covered and later uncovered a spot group near the center of the solar disk, the observed intensity at radio frequencies dropped sharply and then rose again.

An eclipse of the sun by the moon, when viewed in an optical telescope, passes through four significant positions known as first, second, third, and fourth contact. First contact occurs when the edge of the moon appears just to touch the edge of the sun. When the

High-frequency radio waves from the sun were collected by this 10-foot radar mirror and focused on the antenna of a high-frequency receiver. Signals thus received were amplified and applied to an automatic recorder, providing charts of intensity versus time.

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Charles Sawyer, *Secretary*

National Bureau of Standards
E. U. Condon, *Director*

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Contents

moon covers the sun completely, second contact is said to occur. Third contact takes place when the sun again becomes visible, and fourth contact marks the instant at which the edge of the moon finally leaves the edge of the sun.

If the radio-frequency brilliance of the solar corona had been symmetrical, a minimum of observed intensity should have occurred at the time of optical totality, that is, between second and third contact. Actually, however, the minimum occurred a few minutes after

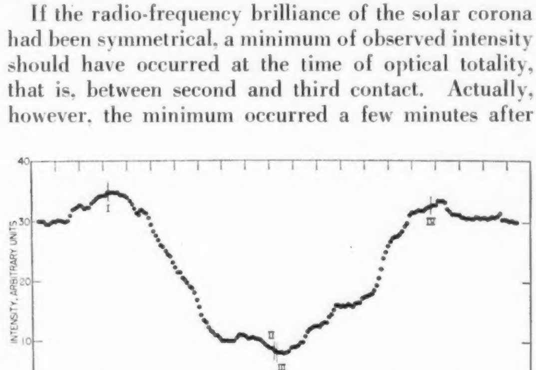


Chart of intensity versus time for 65-megacycle radiation received from the sun during its eclipse by the moon on September 11, 1950. Roman numerals indicate instants of first, second, third, and fourth contact.

totality at all three wavelengths. This was probably due to assymmetry of the corona caused by a group of spots near the east limb of the sun.

At first and fourth contact the apparent intensity rose about 10 percent above that of the unobscured sun. The explanation of this effect is not yet clear; it may be due to reflections of solar energy from the surface of the moon at grazing incidence. Diffraction around the edge of the moon could not have been the cause, as waves of kilometer rather than centimeter length would have been required. The possibility that this unexpected rise in intensity might have been caused by reflections from the landscape near the apparatus is now under investigation.

Effects of Prior Stress on the Fatigue of Aluminum Alloys

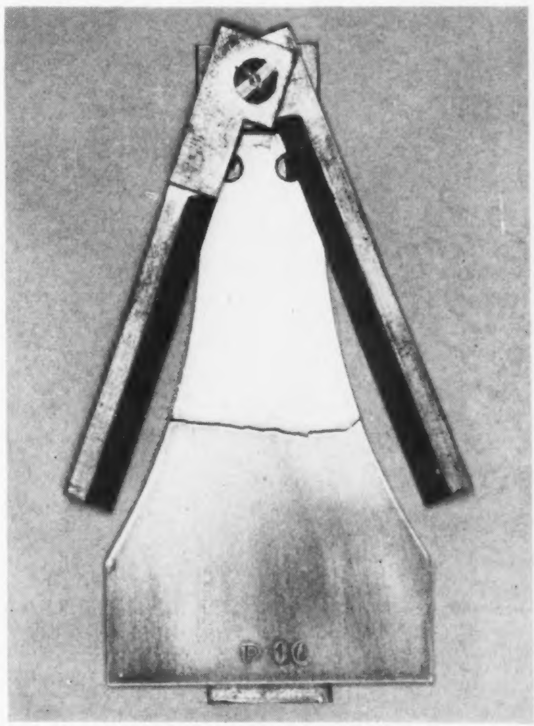
The life of aluminum alloys that are subjected to vibration and other repeated or fluctuating stresses may be materially affected by applying stress to the material before it is placed in operation. Recent investigations at the National Bureau of Standards have shown that this treatment, known as prestressing, in some instances increased the fatigue life manyfold. This was especially noticeable at lower stresses when a comparatively small number of cycles of dynamic prestress were applied. On the other hand, there were cases in which little if any improvement resulted, and at some stresses the fatigue life was shortened by the prestress. These studies were carried out by J. A. Bennett and J. L. Baker in the Bureau's mechanical metallurgy laboratory to evaluate the effects of both static and dynamic prestress on the fatigue properties of structural aluminum alloys. Similar studies have been previously made on aircraft steel.

A metal will often fracture when a pulsating load is applied for long periods of time, even though the maximum stress is much less than that which the metal can withstand if the load were steady. This phenomenon, known as fatigue, is the primary cause of failure in machine elements and other structural members to which varying loads are applied in service. Because of this, the fatigue properties of structural materials are important in the design of dynamically stressed structures. These properties are usually studied by applying a fluctuating load of constant amplitude to a specimen and counting the number of cycles that are required to fracture the specimen. In tests of aluminum alloys, it is not uncommon to find fractures occurring after as many as 500,000,000 cycles of stress, the number of cycles to fracture decreasing as the stress amplitude is increased.

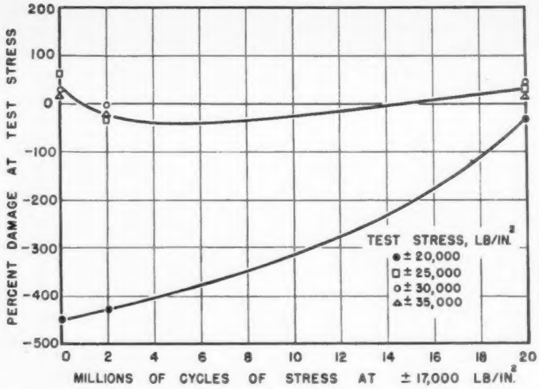
One of the difficulties encountered in applying results of laboratory tests to practical construction arises from the fact that, in many structures, the stresses vary in a random manner. An airplane wing, for example, must support not only the weight of the plane, which is a steady load, but also a fluctuating load due to vertical gusts. To approximate this situation, the cumulative effect of fatigue stressing at two or more different amplitudes was evaluated, using aluminum alloy sheet specimens.

Two means of prestressing were employed. In the first, a rather high static load was applied to the specimen before the start of the fatigue test. In the second, the specimen was stressed in the fatigue-testing machine for a predetermined number of cycles at one amplitude, and then carried to failure at a second amplitude.

Conventional repeated-bending fatigue-testing machines were employed. In these machines one end of the specimen is held fixed in a vise while the other end is deflected up and down by means of an adjustable, motor-driven eccentric and crank. The design of the specimen, however, was new and was found to have several advantages over the usual type. Another innovation was a jig that measured the specimen before testing and automatically located the point at which the stress in the specimen would be at a maximum.



A new design of specimen was used in studying the effect of prestress on the fatigue life of aluminum alloys. The special jig measures the specimen and automatically locates the point of maximum stress. The manner in which fracture took place is also shown.



Specimens of 24S–T aluminum alloy sheet were stressed at 17,000 pounds per square inch in the fatigue-testing machine for a given number of cycles and then carried to failure at another stress. The fatigue life of the prestressed specimens is expressed as a percentage of the life of the original material. Negative values indicate a longer life for the stressed specimens.

The static prestress studies were made with Alclad 24S–T sheet, and all fatigue tests with this group of samples were operated in unidirectional bending; that is, the specimen was bent in only one direction from the "no load" position. First a sufficient number of specimens were tested without prestress to give the typical relationship between stress amplitude and number of cycles to fracture for the original material. Then a static load was applied to the remainder of the specimens before starting the fatigue test. In some cases the bending load in the fatigue test was in the same direction as the static load; in others these directions were opposite.

At the higher test stresses (25,000, 30,000, and 35,000 pounds per square inch), the effect of the static prestress was negligible. However, at the test stress of 20,000 pounds per square inch, there was an appreciable decrease in life for the specimens prestressed in the direction opposite to that of the subsequent fatigue stress. On the other hand, there was a slight increase in life for the specimens with a prior static stress in the same direction. There was thus a 10 to 1 difference in life between these two sets of specimens.

The tests for evaluating the effect of dynamic prestress were made on specimens of bare 24S–T sheet. The fatigue loading was applied in completely reversed bending. That is, the specimens were deflected equally to each side of the no-load position. The prestress amplitude was applied for a given number of cycles before the specimen was carried to failure at the test stress. Three values of prestress amplitude were used and four test stresses.

At the two higher prestress amplitudes (22,500 and 32,500 pounds per square inch) fracture occurred earlier in the prestressed samples than in the original material. It seems therefore that a portion of the fatigue life of the alloy is used up by the prior stress. Within experimental error it was found that this portion was approximately equal to the ratio of the number of cycles run at a given prestress to the number of cycles that will cause failure at that stress.

For the lowest prestress, however (17,000 pounds per square inch), the behavior was entirely different. At a slightly higher test stress (20,000 pounds), there was a noticeable improvement in the life of the specimens. Two thousand cycles and 2,000,000 cycles of prestress produced an increase of more than 400 percent. Even at 20,000,000 cycles, the increase was of the order of 33 percent.

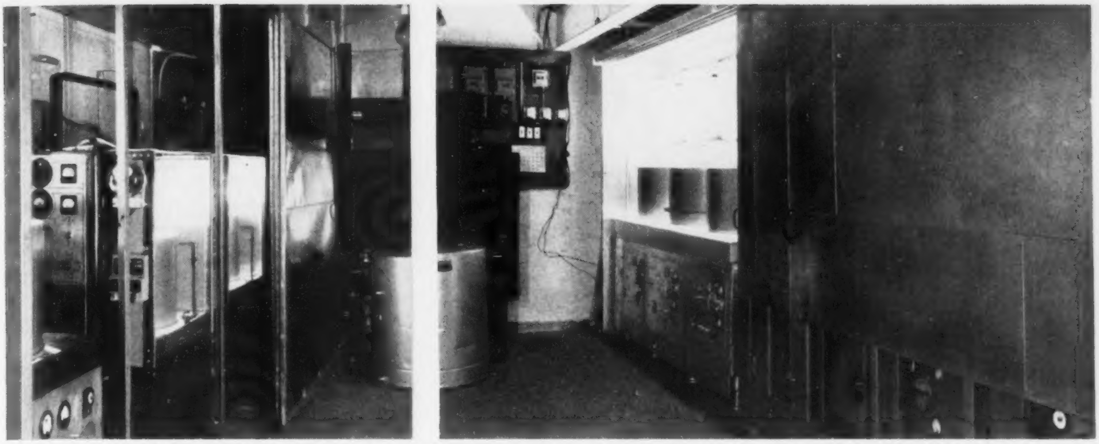
The immediate importance of this work is the possibility of improving the fatigue life of structural members by prestressing. The work is also significant in that it may aid in solving the fundamental problem of determining the mechanism of fatigue failure in metals.

New Laboratory for Durability Studies of Protective Coatings

A special laboratory, recently designed and constructed by the Building Technology Division of the National Bureau of Standards, eliminates the major difficulties that have in the past led to anomalous results in the accelerated durability testing of exterior covering materials. Developed primarily for studying organic coating materials such as asphalts, tars, and paints, the new facilities are sufficiently flexible to meet the requirements of most materials exposed to weathering.

Materials intended for outdoor use are frequently exposed in the laboratory to regular cycles of artificial sun light, heat, and water for the purpose of hastening their deterioration. Although such exposure—called accelerated weathering—is generally accepted as a means for determining the relative resistance of similar materials to weathering, results obtained by different laboratories, and even by the same laboratory, do not always show good agreement. This lack of correlation results from variables inherent in the testing procedures that have in the past been largely uncontrolled. These include solids content of the water supply, fluctuations in the light intensity, and irregular operation of the system due to failure of one or more functions while the others continue to operate.

Automatic control of all functions, and of the temperature and purity of the water within narrow limits, assures uniform operation at all times of the Bureau's improved accelerated weathering laboratory. The room, 16 by 25 feet in size, is maintained within ±1° C of any desired working temperature, at present 27° C. The relative humidity is not controlled directly, but



Over-all view of the new lab for accelerated durability testing of exterior coating materials. In the hood at the right are six weathering machines built at the Bureau and based on the enclosed carbon arc as a source of light. The hood on the left encloses four modified commercial weatherometers. The water-conditioning equipment is located above the machines on the right and the air conditioner in the background, center.

remains in the range of 40 to 60 percent as a result of the subcooling of fresh air brought into the room. The floor area is divided into three portions: a central working space and two areas enclosed in hoods to house the testing machines.

In one hood are six machines built at the Bureau to utilize the enclosed carbon arc as a source of light. The operating range of each light is regulated at 130 to 145 volts and 15 to 17 amperes by means of chromel C ballast resistors in series with the arc. An aluminum drum 31 inches in diameter and holding sixty exposure panels ($2\frac{3}{4}$ by 6 inches) is rotated around each arc at a rate of 1 revolution per minute. Air at ambient conditions is circulated around the panels at a low velocity until they reach a predetermined maximum temperature. At this time a thermo-sensitive element mounted in one of the panels turns on the high-speed blower, which materially increases the air flow and thereby reduces the panel temperatures. Deionized water, controlled by a cycle clock, can be sprayed on the test panels for any portion of their exposure period.

The heart of each machine is a time-delay relay that turns off all functions of that machine if the arc should cease to operate for a period in excess of 30 seconds. Voltage and current are continuously indicated, while the running time and power consumed by the arc are recorded by suitable instruments on each machine. Wiring circuits have been designed to take advantage of the 2-percent voltage control supplied the Bureau.

The other hood encloses a modified commercial open-drum Atlas Weatherometer, two twin-arc Weatherometers, and an Everready X–1A machine. These are controlled in a manner similar to that of the other machines.

An air conditioner of tremendous size would be required to control the temperature of the space around all 10 machines, which dissipate 39 kilovolt-amperes of energy. This temperature is therefore regulated by blending various amounts of outside corridor air (ranging from 15° to 35° C) with conditioned air at 25° ±1° C. The resultant mixture is distributed to the machines in each hood by a 2,000 cubic-feet-per-minute blower with a proportioning damper in its intake plenum. The blended air is distributed in turn to the vicinity of each machine by aluminum ductwork. Further conditioned air is drawn through a 2-inch opening along the floor of each of the hoods by an exhaust blower on the hoods that removes about 30 percent more air than is delivered by the ducts. In this way, the ambient air at each machine is maintained at 29° ±4° C.

Water-conditioning equipment, located on a balcony above one of the hoods, delivers recirculated, deionized water with about 1 part per million of dissolved solids at any desired temperature between 4° and 25° C, ±1° C, to the six machines in that hood. At present, to introduce a cyclic thermal shock to asphalt exposure panels, the equipment is operating at 5° C and 25 pounds per square inch. The pH of the water is maintained by the deionizer at 6.2. Water for the other machines is delivered at room temperature and a pH of 6.0 by another deionizer. All machines can be operated with tap water if deionized water is not required.

Because accelerated durability testing of exterior coverings does not at the present time permit a quantitative correlation with actual weathering, the National Bureau of Standards has constructed a set of exposure decks on the roof of the laboratory building that will hold 3,000 test panels. Materials are thus exposed concurrently on the roof and in the controlled laboratory. Data from these studies should provide some statistical correlation between outdoor weathering in the Washington, D. C., area and in accelerated durability testing in each of the several types of machines.

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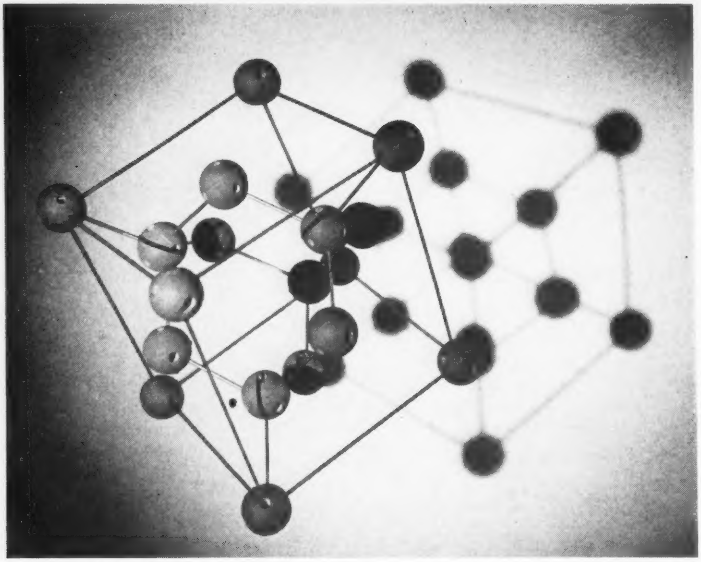


**Silicon and germanium, characterized by
diamond lattice in which each atom is te
hedrally bonded to four nearest neighb
have played a major role in solid state e
tronics. Study of the motion of elect
in structures of this type has led t
better understanding of semiconductors.**

Electrons in Solids

Studies of electrons in free space and of their interactions with electromagnetic fields and isolated particles, such as photons, atoms, or ions, have led to a rather complete picture of their behavior in these comparatively simple situations. The theoretical information so obtained is contained in the laws of quantum mechanics and is reflected in such subjects as atomic or molecular structure and physical electronics. Parallel with these fundamental studies there has been an enormous growth of applied electronics based on vacuum tubes and other devices using electrons in dispersed systems.

Vital parts of any electronic system, however, include components where the electrons are not free but are confined to solids. These range from wiring and resistors to rectifiers and photocells. Although some progress has been made toward a theory of conductivity in metals before the development of quantum mechanics, there was no well-established picture of the mechanism of conduction that could explain the large variations in conductivity encountered in passing from metals through semiconductors to insulators or the variety of other effects observed. One of the major triumphs of quantum theory has been the fact that such a picture can be suggested even though the behavior of electrons in a solid presents a difficult problem that cannot be considered completely solved.

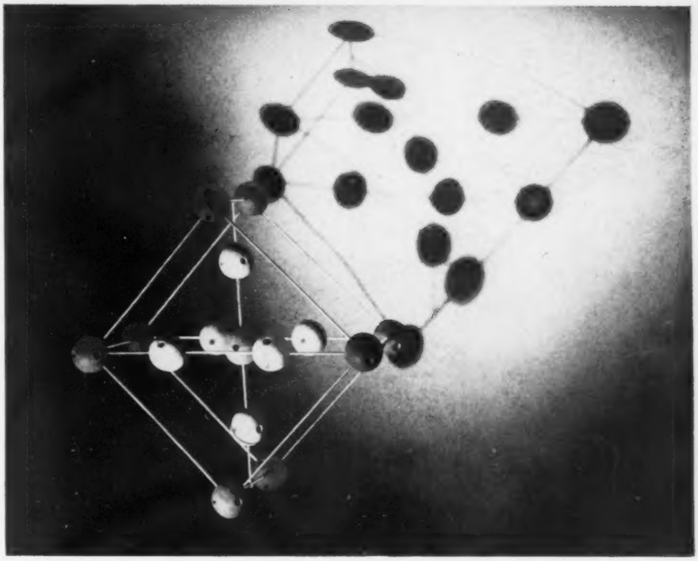
The practical aspects of solid state electronics have provided a constant stimulus to further study. This has resulted in the development of a number of solid state electronic devices including such diverse accomplishments as the galena, or lead-sulfide, crystal detector of the earliest days of radio and the phosphor in the screen of a television set. The first of these, the galena crystal detector, makes use of an extremely interesting phenomenon found at many semiconductor metal contacts. It is frequently observed that current flows through such a junction much more readily in one direction than the other; that is, the junction rectifies. While the galena crystal was promptly replaced by vacuum-tube detectors because of its unreliability, there were inherent features that contained the germ of eventual success. For example, no filament or heated cathode is needed, with a consequent saving of power and elimination of undue heating; no warm-up time is needed; and finally, the device can operate at very high frequencies.

A much more successful solid state electronic device that has been known for some time is the copper oxide power rectifier. This rectifier—similar in principle to the galena crystal detector—is designed to rectify considerable amounts of low-frequency power rather than small amounts of radio-frequency power. This unit and the selenium and magnesium-copper sulphide types developed later showed the practical nature of dry rectifiers and served as a great stimulus to the study of electrons in solids. During World War II the crystal detector was perfected for use in microwave radar. This development, which used silicon and germanium instead of lead sulphide, considerably clarified the nature of semiconductors. Out of this study came the solid state triode, the transistor, which was discovered by Bardeen and Brattain of the Bell Telephone Laboratories.

The phenomenon of rectification is not the only interesting property of electrons in solids. According to present theory, a free electron can move in a perfectly regular periodic crystal without being deflected. At temperatures above absolute zero the thermal vibrations of the lattice disturb the regularity so that the electron is scattered and thus the material has a finite resistivity. Disturbances of the structure by vacant

Electronics

become one of the most active fields of modern
of semiconductors, was greatly stimulated by the
tensively used in radar work and are now finding
recent discovery of the transistor, a crystal triode
amplifiers, has intensified interest in the subject.
practical applications, physical interpretation of
For this reason, the major current objective of the
Standards concerns the fundamental study of semi-
crystal properties are also being investigated in
num utilization of these and other new materials in



Titanium dioxide in the crystalline form of rutile is currently under study at the Bureau. This material, when made semiconducting by the addition of foreign ions or loss of oxygen, exhibits properties that show promise for practical applications.

lattice sites or foreign atoms are very likely to affect the motion of the electron, which may become trapped by the electrical field of the imperfection. Such trapped electrons have optical absorption bands in the visible region for alkali-halide crystals and the study of these so-called "F centers" has provided some of our most detailed information about electrons in crystals. Such trapped electrons are vital to the luminescence of materials. Similarly, optical absorption in semiconductors provides the basis for some types of photocells. Another closely related effect results in the use of crystals as counters for high-energy nuclear particles.

Band Theory of Solids

The theoretical model that may be used to provide a picture of all these phenomena is known as the band theory of solids. When isolated atoms or ions are brought together to form a perfectly regular crystal lattice, their discrete allowed electron energy levels become broadened by interaction effects. The resulting allowed energy bands for a crystal may be widely separated by unallowed energy states or they may overlap; the bands may be filled with electrons, partially filled, or empty. These different band structures can be directly correlated with differences in electrical properties.

In figure 1, a, the lower allowed band of energies is only partially filled, and there are allowed states available to an electron, differing only slightly in energy from those already occupied. If an electric field is applied to a solid with this band structure, an electron at the top of the filled states may acquire enough energy from the electrical field to enter one of the empty, allowed states above it and become free to move in the field direction. This is the mechanism of electrical conduction in a crystal. This picture applies to the alkali metals, which have only one valence electron in an outer *s* state. As two electrons may be in the same *s* state, the band is just half full.

In figure 1, b, the allowed bands overlap—a condition believed to be typical of the alkaline earth metals. The *s* band is completely filled, as there are two *s* electrons, but the *p* band of next higher energy overlaps the *s* band so that an electron may be accelerated as before. The alkaline earth metals are thus electrically conductive. In figure 1, c, the lower band is completely filled and is widely separated from the next allowed band. A crystal with this band structure is an insulator.

The behavior of semiconductors may also be explained with the aid of the band picture as suggested by A. H. Wilson. Three possible cases are represented in figure 2.

An intrinsic semiconductor, one that behaves as a semiconductor even when no impurities are present (fig. 2, a), has an energy gap ΔE comparable to kT between the completely filled band and an empty allowed band, so that electrons may be thermally excited from the filled to the empty band. When this happens, not only are the excited electrons accelerated by the field, but, since there are now a few empty allowed states in the normally filled band, the remaining electrons may be accelerated as well. The situation is analogous to a filled checkerboard on which no moves are possible until a piece is removed. This mechanism, in which the electron vacancy behaves like an electron with an effective positive charge, is known as "hole" conduction. Such intrinsic semiconduction is usually only found at rather elevated temperatures.

Most semiconductors depend for their conductivity on impurities within the crystal lattice; that is, they are extrinsic semiconductors. Figure 2, b, indicates a possible effect of adding an impurity to a crystal that

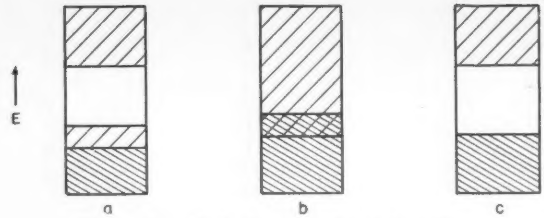


Figure 1. Typical energy bands in solids.

would normally be an insulator. The foreign atoms introduce new isolated energy levels into the band diagram. In figure 2, b, these levels are at a small distance ΔE below the empty band. If ΔE is comparable with kT, the foreign atoms may ionize and provide electrons in the conduction band. Impurities of this sort are called "donors". This material is thus an "n-type" semiconductor, which indicates that the sign of the charge carriers is negative.

The third type of semiconductor in figure 2, c, is the converse of that just described. The impurity levels are close to the filled band, and may be ionized by accepting an electron from the filled band leaving a hole in that band. Conduction is then by holes, and the name "p-type" indicates the positive sign of the charge carriers. Impurities of this sort are known as "acceptors". New levels or irregularities may be introduced into the characertistic bands of the perfectly regular, infinite crystal, not only by foreign impurities or excess atoms of one constituent of the crystal, but also by the presence of free surfaces and lattice defects. Such disturbances may be effective as electron traps and have a great influence on conductivity.

While the concept of bands in crystals may seem somewhat abstract, it is possible in some simple cases to give a more concrete physical picture of the situation. For example, silicon and germanium crystallize in the diamond lattice in which each atom is tetrahedrally bonded to four nearest neighbors. Each bond consists of a shared pair of electrons, and these electrons in their normal unexcited state constitute the filled band. If an atom with a normal valence of 5, say arsenic, is introduced into the lattice, four of its valence electrons may be used to form shared-pair bonds with its neighbors; the fifth, however, may be thermally released, ionizing the atom. It then becomes free to move in the lattice and conduct a current. This is the situation indicated in figure 2, b. Similarly, the addition of a trivalent atom such as aluminum causes a disturbance in the electronic structure because only three shared electron-pair bonds may be formed to neighbors. If an electron is drawn from some other bond in the lattice to complete the tetrahedral bonding around the aluminum, that is, ionizing the aluminum, there results an electron deficiency in the structure, or in terms of the band picture, a hole in the filled band which of course can move from atom to atom. These same energy-level diagrams may be used to explain rectification at metal-semiconductor contacts and the various photo effects, although the details are more complicated.

The work in solid state electronics at the National Bureau of Standards is centered on a basic study of the properties of a few interesting semiconducting materials. Related problems dealing with lattice defects in crystals are also being investigated since, as indicated above, the defects may have a marked effect on the crystal properties.

The experimental study of the electrical properties of solids involves the investigation of conductivity and the Hall coefficient. From the variations of these quantities with temperature and other parameters, it is possible to obtain the information needed to understand the mechanism of conduction in the crystal and to evaluate the material for use in practical electronic devices. This information includes the number of charge carriers n, their sign, their mobility u, and the activation energies ΔE_1 for conduction.

In a typical experiment, the conductivity (σ) is found from a measure of the potential drop along a sample of regular shape while a current is flowing through it. For semiconductors, however, a measure of conductivity alone is not sufficient to determine n and u separately. The necessary additional information is obtained from the Hall effect, discovered in 1897 by E. H. Hall. Hall observed that when a conductor in which a current is flowing is subjected to a magnetic field perpendicular to the current direction, charge carriers tend to migrate toward one side of the conductor, producing an electric field. This effect is represented schematically in figure 3.

The Hall coefficient, R, is the constant of proportionality between the voltage produced and the product of current and field strength. The sign of the voltage is an indication of the sign of the charge carriers; the usual convention is indicated on the diagram. It may be shown that the mobilities may be obtained from the product of the Hall constant and the conductivity. Theoretical expressions have been derived relating the mobility of electrons to their mean free path and also giving the number of charge carriers as a function of temperature.

The measure of the Hall coefficient and conductivity as functions of temperatures are ordinarily made simultaneously over as wide a temperature range as is convenient. An apparatus of conventional design for studies of this type using direct current has been assembled at the National Bureau of Standards.

Typical measurements made with this equipment are shown in figure 4, where log R and log ρ (where $\rho = 1/\sigma$) are given as functions of the reciprocal of

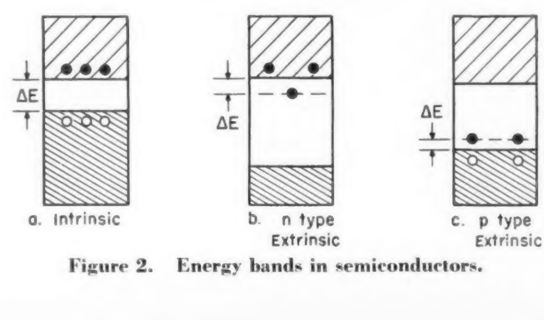


Figure 2. Energy bands in semiconductors.

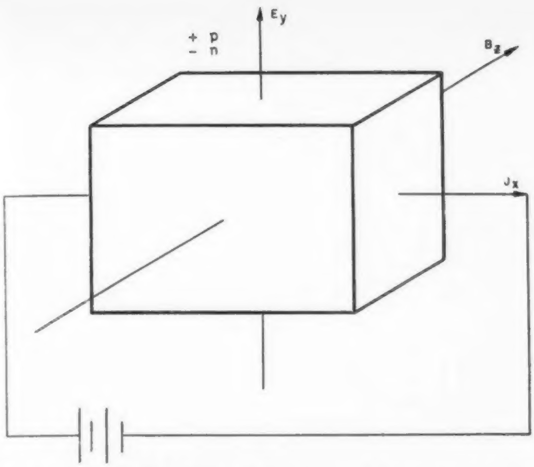


Figure 3. Hall effect. When a conductor carrying a current of density J_x is placed in a magnetic field (B_z) at right angles to the current, a voltage (E_y) is developed in a direction perpendicular to both J_x and B_z.

the absolute temperature for a sample of germanium containing 0.001 percent of aluminum. As the impurity is an acceptor of electrons, the sample is *p*-type at low temperatures. The slopes of the curves for ρ and R at high temperatures, where electrons may be thermally excited from the filled to the conduction band, indicate an activation energy, E, for intrinsic conductivity of 0.76 electron volt. Because electrons have greater mobility than holes do, the sample is *n*-type in this range. Log R changes sign as the sample becomes *p*-type at lower temperatures, where the impurities have a decisive influence.

While the properties of germanium at normal temperatures have been studied in a number of laboratories, work is in progress at the Bureau to determine the suitability of germanium for use as a resistance thermometer at very low temperatures. The measurements shown in figure 4 were made in connection with this work.

An important portion of the semiconductor work at the National Bureau of Standards has been concerned with the properties of titanium dioxide in the form of rutile. When pure and of exact chemical composition, this material is an excellent insulator, the energy gap in figure 1, c, being about 3.6 electron volts. It may be made into a semiconductor by the addition of foreign ions or by treatment with hydrogen at high temperatures to cause a loss of oxygen and consequently an excess of titanium in the lattice. When prepared in this latter way, it is an *n*-type semiconductor (fig. 2, b) with properties that show promise for practical applications.

Another material under study at the Bureau is "grey tin", which is a low-temperature form of ordinary or "white" tin, having the same crystal structure as silicon or germanium. Recent studies in other laboratories have shown that it is a semiconductor with a very low activation energy and a high mobility both of holes and electrons. Precise measurements of these quantities are not yet available because of the difficulty in preparing a sample in a form suitable for measurement. The work thus far indicates, however, that the substance will be of considerable theoretical and practical importance when the problems of its preparation are solved.

Lattice Defects

As mentioned above, defects in crystal structure may serve as electron traps and may thus have a great influence on the electrical properties of solids. Although some type of lattice defect seems to be present in all real crystals, the situation is most clearly understood in ionic crystals. The mechanism of the observed ionic conductivity in the alkali-halide crystals is difficult to explain on the basis of the perfectly regular lattice indicated by X-ray studies, since the field strengths at which conduction is observed are much smaller than that needed to move an ion from a lattice site. It was suggested by Frenkel that when the crystal is in thermal equilibrium, a number of ions have actually left their sites and migrated to interstitial positions in the lattice, leaving behind a vacant site. The crystal is still electrically neutral because the charge of the interstitial ion is compensated for by the charge of opposite sign at the vacant site. An alternative suggestion by Schottky and Wagner assumes that the crystal contains equal numbers of positive and negative ion vacancies. These two explanations are indicated schematically in figure 5.

Either mechanism may be used to explain ionic con-

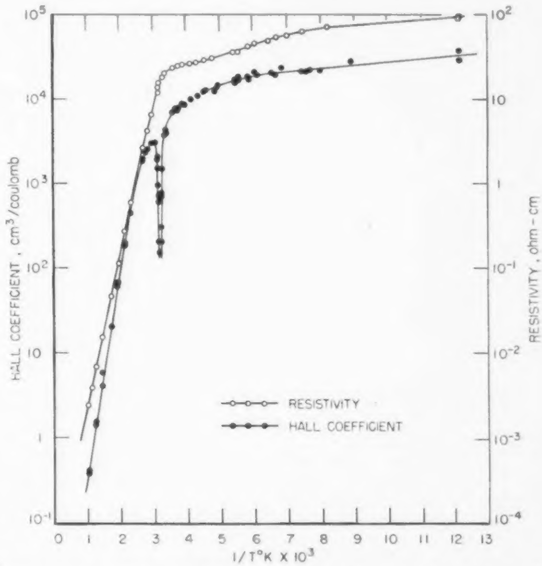


Figure 4. Hall coefficient and resistivity as functions of temperature for *p*-type germanium. These measurements were made at the Bureau to determine the suitability of germanium as a resistance thermometer at very low temperatures.

Bureau scentists are using specially designed apparatus for studying the internal friction of crystals. The decay of free torsional oscillations of a composite piezoelectric resonator is observed. From these measurements, it is expected that the effects of crystal imperfections on semiconducting properties will be revealed.

ductivity, as the vacancies or interstitial ions can migrate under the influence of the field; but there are some differences between them. The Frenkel defect can carry charge either by the motion of the interstitial ion or of the vacant site, while in the Schottky case only vacancies are present. Frenkel defects may be formed anywhere in the crystal, but Schottky defects seem to form only at free surfaces and then to diffuse into the interior of the crystal.

The number of these defects in thermal equilibrium in a crystal can be calculated from an increase in entropy on distributing n defects on N lattice sites. The mobility of the defects may be calculated in terms of the activation energy required to move the vacancy to an adjoining site in the lattice. In finding the number and mobility of the defects, the conductivity alone does not provide enough information. Unfortunately, reliable Hall effect measurements are not obtainable because of the very low mobility of the ions, so alternative methods must be used.

One method, suggested by Koch and Wagner, is to make the number of defects independent of temperature by the addition of a divalent ion impurity. To preserve electrical neutrality, a positive ion vacancy is formed for each divalent ion in the lattice. The variation of the conductivity with temperature then depends only on the mobility, so the activation energy may then be found. There is some question, however, whether the assumption that each divalent ion produces a positive ion vacancy is completely correct, since any clustering of the foreign ions would modify the neutrality requirements and the degree of aggregation would be expected to change with temperature. This is particularly true when relatively large amounts of the foreign ion are present.

Another method of investigation has been proposed by Breckenridge. In a study of the dielectric loss of crystals that had been heat-treated to introduce relatively large numbers of defects, and of crystals containing divalent foreign ions, he found dielectric loss maxima at certain frequencies and temperatures which he attributed to the reorienting of pairs of defects in the alternating-current field. These defect pairs are formed by the electrostatic attraction between vacancies of opposite sign or between divalent impurity ions and vacant sites. The height of the dielectric loss maxima can be related to the number of paired vacancies and the activation energy for pair reorientation can be found from the temperature and frequency at which the maximum loss is found. This method, of course, does not give the activation energy for moving single vacancies directly, the value for pairs being appreciably less than for single vacancies. The degree of association of the defects is not known precisely either, so that information about the number of single defects cannot be found directly in this manner.

In general, the available evidence suggests that there are about 10^{15} or 10^{16} vacancies per cubic centimeter, that is, a molefraction of 10^{-5} or 10^{-6}, and that the activation energy for the migration of a vacancy is of the order of 0.7 electron volt, while the energy to form a Frenkel or a Schottky defect is about 2.5 to 3.0 electron volts for the typical alkali halides. These results are also in rough agreement with the experiments on the density of electron traps in these crystals. The methods previously used for the study of lattice defects apply only to ionic crystals with low conductivity, whereas much of the work of interest is being done on covalent crystals, such as diamond, or on conducting crystals such as germanium.

A mechanical analogue of the measurement of dielectric loss is proving of considerable interest for the study of crystal imperfections and is under investigation at the National Bureau of Standards. In the Bureau's apparatus the internal friction in the crystal is studied by observing the decay of free torsional

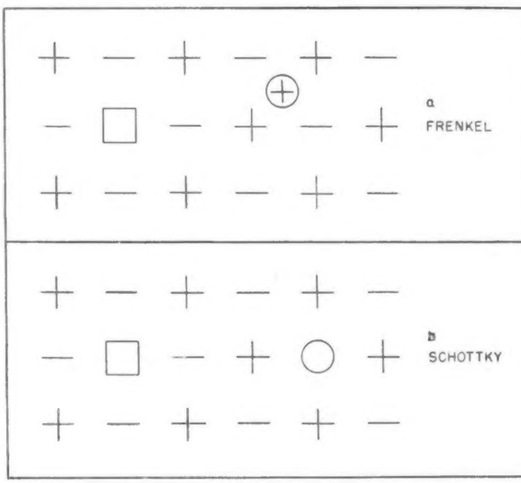


Figure 5. Lattice defects in ionic crystals.

oscillations of a composite piezoelectric resonator, which consists of a Y-cut quartz bar with the crystal to be studied cemented at one end. Plots of Q, the reciprocal of the elastic loss, as a function of temperature show maxima typical of a stress relaxation process in the crystal.

The interpretation of such processes in metallic crystals has been considered in detail by Zener, who showed that elastic stress relaxation with consequent absorption of energy can arise from a number of causes: thermal current flow, grain boundary diffusion, and atomic diffusion. Of these, the process of atomic diffusion should be the only one of interest in an ionic crystal.

Some preliminary values of activation energies for ion migration in ionic crystals have been obtained that are in excellent agreement with previous work by other methods. When the results are analyzed in greater detail, it may be possible to get considerable information about lattice defects. The method should be useful in the study of crystals not readily investigated by other techniques, namely, the covalent and conducting crystals. In connection with this program, some studies are being made of the mechanical losses in quartz.

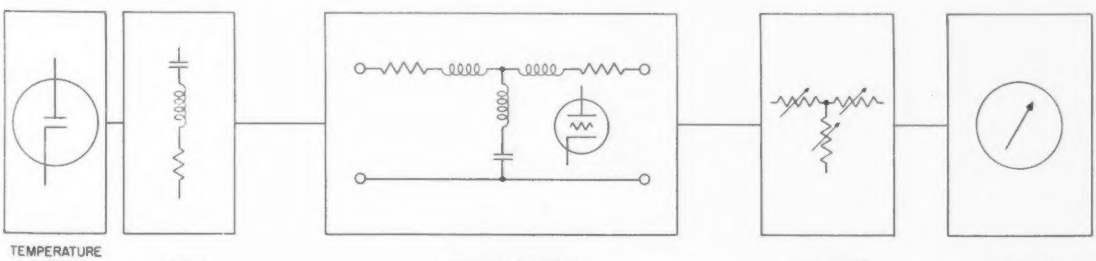
In addition to the fundamental investigations now underway, the Bureau plans to extend the work in solid state electronics to include optical, magnetic and thermoelectric studies of crystals as well. Information obtained in these studies is expected to provide a clearer conception of the electronic character of solids. It is hoped that fundamental information on the properties of solids and the nature of the processes of conduction and rectification will be obtained from this program. Such data will be of valuable aid to researchers in the field of solid state physics.

Noise Figure Standards

The noise figure, a fundamental measure of the quality of linear electrical networks, is of basic importance in radar, telemetering, and all communications. In these systems some of the limitations on reliability, sensitivity, and distance are set by the type and magnitude of noise in the device as well as by the noise produced ahead of the network input terminals. In order to assist laboratories and industry in the evaluation of this important factor, the National Bureau of Standards is offering a calibration service for the noise figure in the frequency range of 500 kilocycles to 30 megacycles. Standards for this purpose have been developed by M. Solow, I. W. Hammer, and P. H. Hass of the Bureau's Central Radio Propagation Laboratory.

The noise figure of a linear network is the ratio of the available noise power at the output (the total network and source noise) to the available noise power at the output source alone. Noise power in an electrical network (i. e., a radio receiver) is generated by the network resistance (Johnson noise) and its vacuum tubes (shot noise). The noise figure is a function of frequency and of the network and source impedance; both are measurable to a high degree of accuracy by various independent techniques. With these important parameters of a unit accurately evaluated, calibration can now be made. Thus, the Bureau's calibration method breaks down into one involving only five components—a temperature limited noise diode, a two-terminal source network, a four-terminal network under calibration, an attenuator, and a sensitive voltmeter.

The equivalent noise resistance used in evaluating the technique utilizes the concept that the noise power from the network can be represented by the Johnson noise of this resistance. Experimental verification of this theory was made with 11 different values of test impedance and at frequencies of 0.5, 4.3, 12, and 30 megacycles. Measurements made with the temperature-limited diode conclusively proved that the equivalent noise resistance was constant for all the values of test network impedance at each frequency. The evaluation has shown that the Bureau's calibration method will yield precise noise figures. It was also proved that this method of calibrating noise figures is valid for a matched or unmatched condition of input impedance. In addition this method may be successfully applied to measuring the impedance of two-terminal networks.



Schematic diagram of the Bureau's noise figure measuring apparatus. This system is used in the calibration service for measuring noise figures of linear electrical networks.

Thus with the theory verified by a wide range of experiments, the National Bureau of Standards is equipped to provide standards for noise figure measurements. Calibrations can be made for high gain, linear, four-terminal networks such as radio receivers and amplifiers (10 to 150 ohms source impedances) to ± 0.2 decibel and at frequencies up to 30 megacycles. Work is still in progress to extend noise figure standards to 300 megacycles.

Apparatus for the Bureau's noise figure calibration service of a four-terminal network. The radio receiver (center background) and a cathode-follower input stage (tube, center foreground) constitutes the four-terminal network. The noise diode is directly to the left of this tube, and the right arm of the "tee" is a two-terminal network simulating the source.

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